RETRIEVAL OF PARTICULATE MATTER CONCENTRATION (PM10) FROM MERIS OBSERVATION AND VALIDATION OVER GERMANY

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ABSTRACT

Information on particulate matter (PM), mostly in terms of PM10 concentration(PM) is commonly used by environmental control agencies for the evaluation of the pollution status of the atmosphere. The characterization of air quality by PM data mainly is made by ground-based measurements. Retrievals of PM from satellite observations are a supplementary information to local or national ground-based observation networks. A retrieval method for PM10 concentrations, using retrievals of spectral aerosol optical thickness (AOT) is described, in von Hoyningen-Huene et al., 2007, has been applied to MERIS L1 data over Germany. Results of PM10 retrievals from satellite observations have been compared with ground-based PM10 measurements of the Federal Environmental Agency, Umweltbundesamt (UBA). AOT alone is more or less uncorrelated with PM10 concentrations from ground. However, the spectral AOT, yielding size information, in combination with estimates of planetary boundary layer (PBL) height yield estimates of PM10 concentrations better correlated with ground observations

1. INTRODUCTION

The determination of particulate matter (PM) from space-borne aerosol observations is a relevant information for environmental control. The basic information is the spectral aerosol optical thickness, which is used to calculate PM concentrations under assumptions to transfer the columnar observation to near surface conditions. PM, such as PM10 concentrations from space-borne observations are required for air quality evaluation and control and can fill in gaps between ground-based stations of the national air quality networks and to get information on PM for regions with no or poor access to ground-based network data. Since satellites give normally columnar observation of the whole atmosphere, and PM data are valid only for the atmospheric boundary layer, the satellite-derived data for columnar PM must be reprocessed to account for conditions at the ground (e.g., at 2m height as observed by ground stations). Therefore the retrieval of PM requires the integration of very different information: (a) aerosol optical thickness (AOT), (b) aerosol type and composition, (c) vertical profile and distribution of aerosol and (d) humidity.

The most approaches, exploring this task in the past, use empirical correlations between AOT and PM observations or simple linear relationships between number concentration and AOT: Fraser (1974), Fraser et al. (1984), Gasso & Hegg (1997, 2003), Kaufman & Fraser (1990). Such empirical correlations, derived for specific regions from AERONET and PM_{10} data (Al-Saadi et al., 2005, Gasso and Hegg; 2003, Chu et al, 2003, Koelemeijer et al., 2006) are of relatively poor quality and cannot be transferred to other regions and aerosol types, because they do not consider the spectral behavior of AOT. The AOT alone is not sufficient for a determination of PM concentration. This is also the case in the PROMOTE approach in Höller et al. (2005). These approaches can serve only as coarse indicators for aerosol concentrations.

In von Hoyningen-Huene et al., 2007 relationships between spectral slope of AOT in terms of the Angström α parameter and size information in terms of the effective radius are used to obtain columnar mass. Assumptions on density and PBL height enabled estimates of PM10 concentrations. This approach has been used now in a first validation study.

2. METHOD OF PM RETRIEVAL

Spectral AOT over land is retrieved, using Bremen AErosol Retrieval (BAER) with MERIS reduced resolution (RR) level 1 data, von Hoyningen-Huene et al., 2003, von Hoyningen-Huene et al., 2006. This approach use the 7 short wave channels of MERIS instrument to derive AOT, $\delta_{Aer}(\lambda)$, which yields the Angström α parameter, the spectral slope of $\delta_{Aer}(\lambda)$. For the conversion of Angström α into size information Kokhanovsky et al. (2006) use a mono-modal logarithmic size distribution, characterized by the effective radius r_{eff} and a fixed mode width $\sigma = 0.8326$. Mie theory is used to derive parameterisations for r_{eff} and extinction factor as a function of spectral slope: $r_{eff} = f_1(\alpha)$, $q_{ext} = f_2(\alpha)$. The relationships for $r_{eff} = f_1(\alpha)$ and $q_{ext} = f_2(\alpha)$ derived are presented in Fig. 1.

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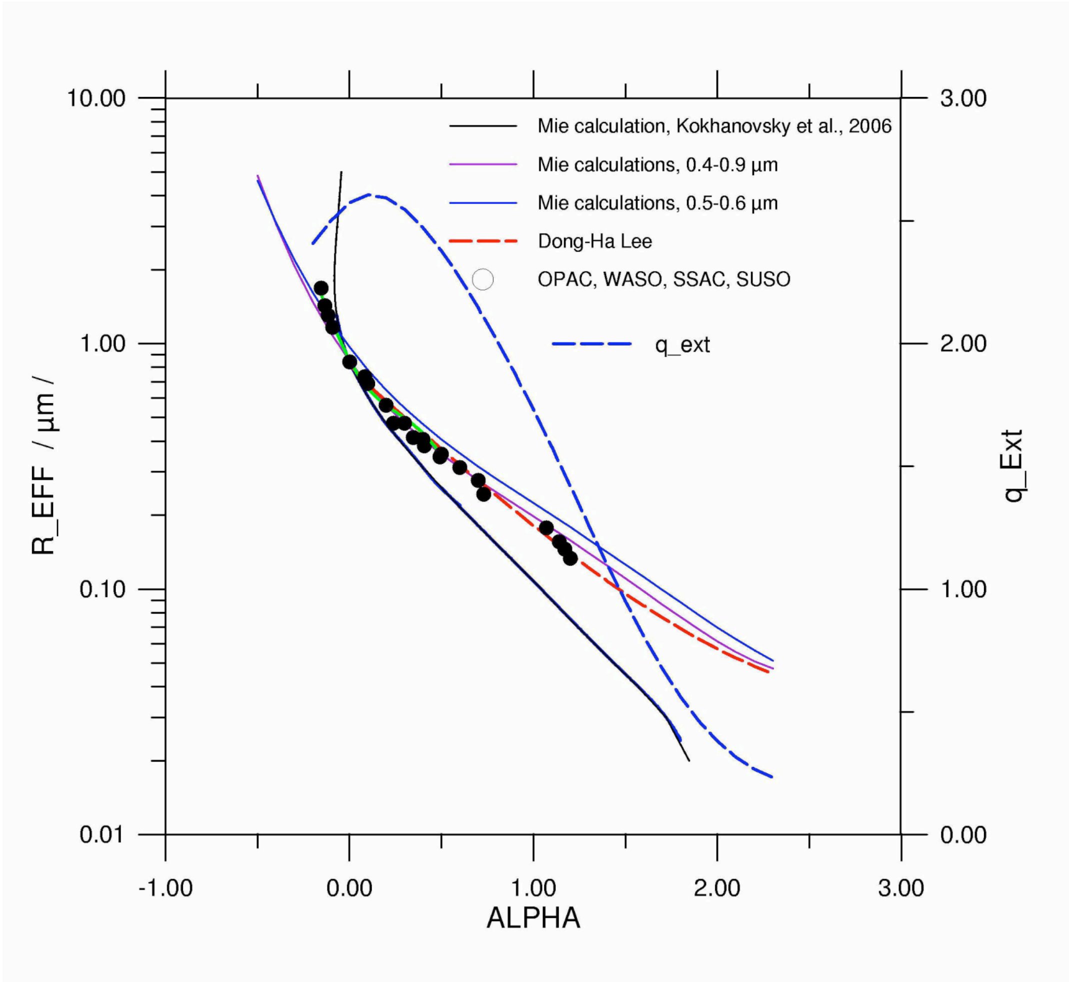

Fig. 1: Effective radius and extinction factor as functions of Angström α-parameter.

The relationships coinciding with that of OPAC modes for different humidity have been used for the PM10 retrieval. Such the number concentration for the monomodal lognormal size distribution n_{Aer} and the columnar mass M_{Col} can be derived, using following equations:

$$n_{Aer} = 8 \cdot \delta_{Aer}(0.412\mu m)\frac{1}{\pi \cdot r_{eff}^2 \cdot q_{ext}}$$

$$M_{Col} \approx \frac{\pi}{6}\rho \cdot n_{Aer} r_{eff}^3 ,$$

with ρ, the aerosol density.

Estimating PM10 concentrations from columnar mass the fraction of AOT within PBL - a - and the PBL height, h_{PBL} is required:

$$PM10 \approx a\frac{M_{Col}(r_{eff}(dry))}{h_{PBL}} .$$

Aerosol density ρ, aerosol fraction within PBL a and PBL height h_{PBL} need to be assessed or determined. They determine the magnitude of PM10 concentration. The density is assumed first to be 1 g/cm³. The fraction of AOT within PBL is assumed as 0.9. The PBL height in a first approach is assumed to be 1 km. However, this validation study showed, that PBL height needs to be variable according the conditions at the MERIS observations.

3. RESULTS AND VALIDATION

The approach, described in section 2 has been applied with 15 different MERIS RR L1 scenes with widely cloud free conditions over Germany. Spectral AOT has been retrieved, using BAER, yielding AOT(0.412 µm) and Angström α-parameter. Using equations and parameterizations above, number concentration, columnar mass and PM10 concentration have been obtained. One example of AOT for the 5. May 2006 is

given in Fig. 2 and of PM10 in Fig. 3. It is a case of pollution transport from Eastern Europe.

Essential for reliable PM10 concentrations is a very restrictive cloud screening, because thin and sub-pixel clouds disturb as well AOT and PM10.

For the validation collocations with ground based PM10 concentrations have been established within a distance of 0.7 and 0.3 km from ground based measurement sites of the German federal country networks, provided by the Umweltbundesamt. The data are hourly or 0.5 hourly averages of PM10 concentrations. The hourly average closest to the ENVISAT over flight time have been used for the inter-comparisons. The sites have been characterized into different types of main influence, like background, rural, urban, industrial and traffic. No correlation between AOT and ground-based PM10 concentration could be found. Although, the histograms of ground-based measured and satellite derived PM10 concentrations look similar, the correlations with a fixed PBL height for all scenes have been almost random scatter plots, except the industrial sites with increased pollution. One Example for background site is presented in Fig. 4. In urban sites and traffic sites high PM10 concentrations of ground-based stations near main roads are not observed by the retrieval. Using constant PBL height a poor correlation between ground-based and retrieved data is obtained:

$$PM10_{Ground} = 0.310 \cdot PM_{MERIS} + 0.51.39$$

with a correlation coefficient r = 0.31 and a standard deviation σ = 18.

In a second approach additionally average PBL height for the different MERIS scenes from ECMWF have been used.

The consideration of an average PBL height corresponding to the different over-flight times of the 15 MERIS scenes used, reduced significantly the scattering of the data and an improved correlation could be obtained. With consideration of scene average of PBL height the following correlation is obtained:

$$PM10_{Ground} = 0.599 \cdot PM10_{MERIS} + 16.357$$

, with r = 0.76 and σ = 9.9. This second approach still did not consider regional variations of PBL height. This needs to be implemented into a future version of the PM10 retrieval approach.

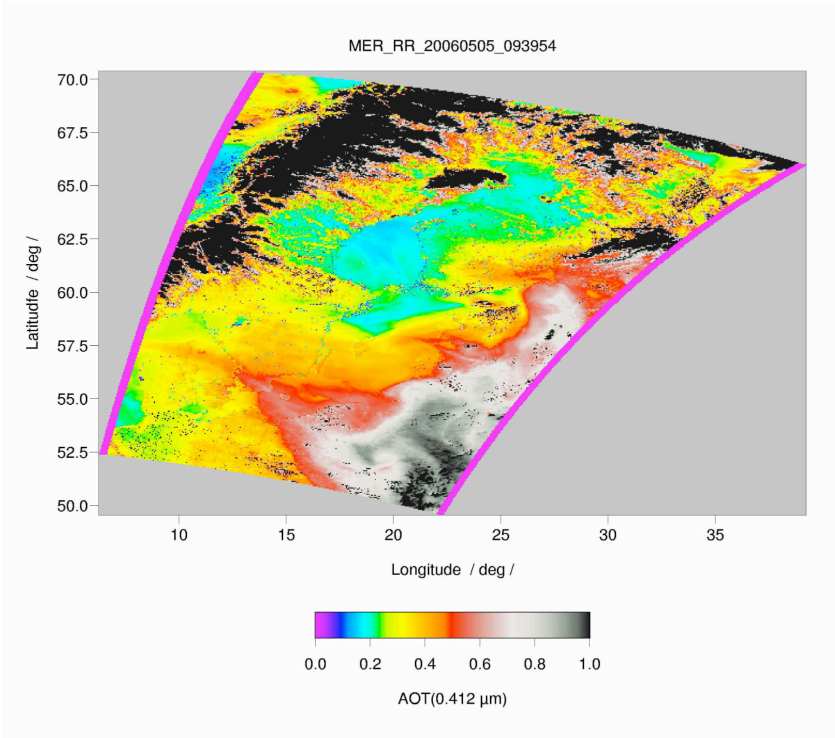

Fig. 2: Aerosol optical thickness of MERIS channel 1 (0.412 µm) of 5. May 2006

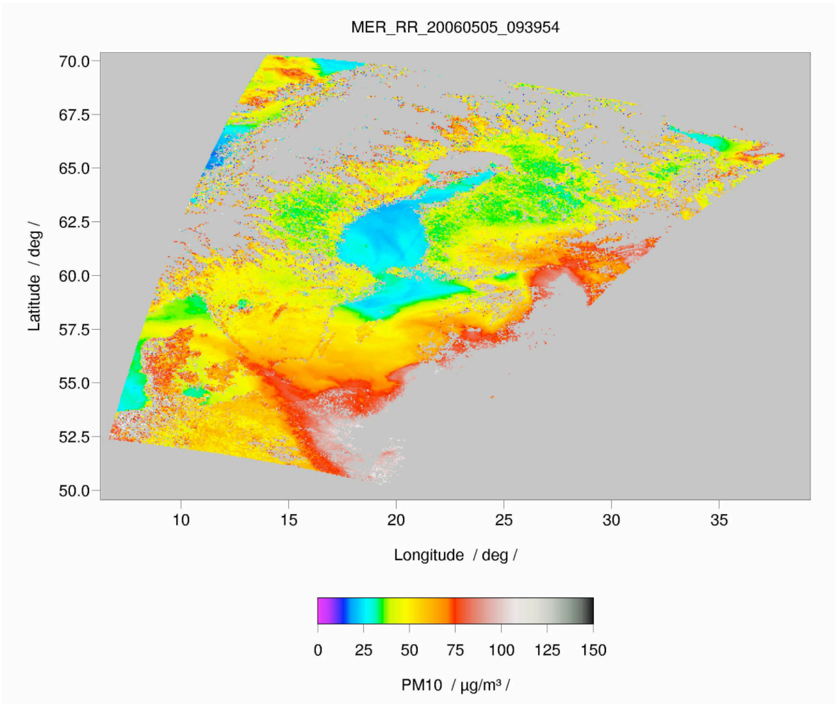

Fig. 3: PM10 concentration for the MERIS scene of 5. May 2006.

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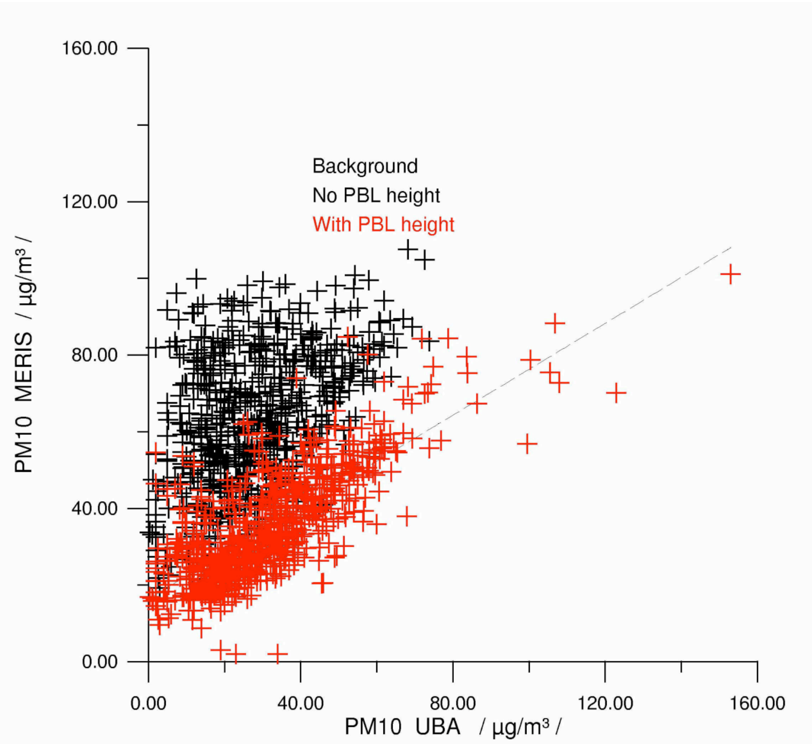

Fig. 4: Intercomparison of retrieved PM10 concentration from 15 MERIS scenesand ground based measurements of PM10 concentrations, provided by the Umweltbundesamt for fixed (1 km) PBL height (black) and variable average PBL height corresponding to the different MERIS scenes.